ENHANCED HEAT TRANSFER FOR VERTICAL BOREHOLE GROUND HEAT EXCHANGERS

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1. INTRODUCTION

The world currently relies heavily on coal, oil, and natural gas for its energy. These fossil fuels are non-renewable and too environmentally damaging to retrieve. In contrast, renewable energy resources, such as solar energy and earth energy, are constantly replenished and will never run out. Nowadays people are more and more fascinating on the technology about heat transfer enhancement and sufficient earth energy utilization. The closed-loop ground source heat pump (GSHP) system can extract the energy from the ground and can reject the energy to the ground. However, as a closed-loop GSHP system, it has no pollution and consumption to the underground water and will not destruct the properties of the underground frame, so that the closed-loop GSHP system is friendly to the environment. Whether there is underground water or not, the closed-loop GSHP is also adapt to any engineering application to extract and reject energy and deposit energy in the ground.

Along with more and more cognition, GSHP will substitute the current products of heating or cooling systems used in building in a coming time. Especially in north China, this system is more significant to solve the problems of the serious pollution in winter and energy consumption. But as we known, the thing has two aspects. Its shortcoming is obvious, which the heat conductivity of the ground is so low that it causes the system to occupy the big area of land and needs a large scale of ground heat exchanger (GHE). Now, to enhance the heat transfer is a focus of this field.

Ozgener and Hepbasli (2005) reviewed the situation of development of GSHP. Ozgener pointed that the main disadvantage of GSHP was the higher initial cost and the GHE efficiency. The enhancement of heat transfer, hybrid system and energy storage may be some good ways and can promote its fast development. Recently some researchers emphasize a new type of GHE to enhance the efficiency and lower the initial cost. Ground heat exchangers using foundation piles have been considered as an effective solution for reduction of the initial cost and increase of heat conductivity, and several types of them have been applied recently (Nagano etc 2005). The method has been approved from 1999 in Japan. Total number of buildings and facilities which adopt this method had achieved more than 300 by the end of 2002. The number will increase rapidly in the urban area because of its high-speed installation, the quiet construction and no disposal of waste soil. Another new type of GHE system (Ooka etc 2005) was created, that some U-tubes were arranged around the surface of cast-in-place concrete pile foundations and were installed against the reinforcing bars used in the cast-in-place concrete pile foundations, so the strength of the foundation pile is ensured. This GHE utilizing the cast-in-place concrete pile foundations of a building has reduced the initial boring cost and the average values for heat rejection which were 186–201 W/m (per pile, 25 W/m per pair of tubes) while cooling. The average COP of this system was 4.89 while cooling, so this system is about 1.7 times more efficient than the common ASHP system. Wärnelöf etc (2005) presentd a novel Compact Collector as GHE which requires only a small area and it can be installed in less than a day. The compact collector is always combined with heat recovery from exhaust air. A new concept (Bertsch 2005) has gained interest which uses a closed, self-circulating CO₂ thermosyphon to extract heat from the soil. Advantages of this system are the higher efficiency compared to secondary fluid loops and environmentally friendliness.

Rybach and Sanner (2000) also reviewed the Experimental and theoretical investigations of GSHP in the field of measurement campaigns and numerical model simulations in Europe. In their paper, they summarized detailedly researched activities and practices in the world. The paper recorded that much work had been conducted over several years to elaborate a solid base for the design and for performance evaluation of borehole heat exchanger (BHE) (Knoblich et al., 1993; Rybach and Hopkirk, 1995; Rybach and Eugster, 1997). While in the 1980s, theoretical thermal analysis of BHE systems prevailed in Sweden (Claesson and Eskilson, 1988; Eskilsson and Claesson, 1988), monitoring and simulation were done in Switzerland (Gilby and Hopkirk, 1985;
Hopkirk, et al., 1988), and measurements of heat transport in the ground were made on a test site in Germany (Sanner, 1986). This layout allowed investigating the temperature distribution in the vicinity of the BHE, as well as the temperature decrease around the BHE at the end of the heating season. Measurements from this system were used to validate a numerical model for convective and conductive heat transport in the ground (Sanner and Brehm, 1988; Sanner, et al., 1996).

Beyond all doubt, today, the initial cost, efficiency and the heat transfer enhancement of GHE take more concern and ensure extensive and economic utilization of GSHP. In this paper the authors investigated a new type ground heat exchanger, the screw core tube bundle inside a hole-tube, which has gotten a great improvement and benefit on the ground heat transfer.

2. TEST SYSTEM

The test system consists of two GHEs in the vertical boreholes, a heat pump, two tanks and pipe network. In the two vertical boreholes, one is 100m×ф 150mm, marked “100#”, the other is 200m×ф 100mm, marked “200#”. Many thermocouples were put inside the borehole to measure temperatures of every depth in which temperature sensors were located. Location depths are 1.5m, 20m, 40m, 60m, 80m, 100m in the 100# borehole and 1.5m, 20m, 50m, 80m, 110m, 140m, 170m, 200m in the 200# borehole, respectively. Meanwhile, temperatures of every inlet and outlet of the components, such as boreholes, evaporator and condenser of heat pump, were measured. Two flowmeters were installed on the outlet of both cooled and heated circuit to measure the flow flux of fluids. Two tanks were packaged by polyurethane foam material for insulation. A multifunctional electrical meter was used for measuring electrical power of the GSHP system. The test system is shown in Fig.1.

The authors designed a new type of core screwed tube bundle which has been used in the ground heat exchangers to enhance heat transfer. It is similar to the type of coaxial vertical borehole GHE. The inside core tube is not only one, but a tube bundle which is screwed into twist shape. A special fluid collector in exit port of the ground heat exchanger employed and these can keep the fluid flow in the state of whirlpool successfully. This multidimensional flow improves the capability of heat transfer in the underground. Obviously it is significant to the conditions of lower velocity and lower temperature difference. The borehole, installation and GHE are shown in Figure 2 and 3.

3. RESULTS AND DISCUSSION

The test investigation contained measuring the initial natural temperature of the ground, temperature distribution field in the working condition, capability of heat exchanger, the different characters of this vertical hole heat exchanger in both heating and cooling process (heating and cooling season).

3.1 Initial ground temperature distribution
Figure 4 shows the initial natural temperature of the 200m depth hole which was tested on 18th October in 2001 in Changchun city, China before it served in heating or cooling process test. The measured result indicated that in this season the temperature of the ground surface was about 11.5°C, the lowest temperature was about 8°C at about 25m depth and about 14.5°C at 200m depth. Since deposition of heating in summer and cooling in winter and the lingering of heat transfer, generally the temperature in the shallower part of the earth is variable, colder in winter and higher in summer. As shown in Figure 4, the temperature measured in autumn is degressive in the shallower part. It deduced that in spring the temperature should be incremental. But the temperature of the deeper part of the ground is not affected by the ambient atmosphere and it approximates to a linear increase. The temperature between 25m and 100m depth increases by 0.025°C/m and under 100m increases by 0.05°C/m.

3.2 Process of Heating and Cooling

In the test, the 100m depth borehole rejected heat to the ground, while 200m depth borehole extracted heat from the ground for studying the heat exchange capability, efficiency and temperature trend of the ground. As shown in Figure 5, 200# borehole can extract the heat about 20kw at the beginning, and then the temperature decreases a little with time, but at least it could supply the heat about 15kw steadily for long time running. Simultaneously, the 100# borehole can rejected the heat about 28kw, at least about 24kw. Power consumption increased, as the ground temperature of extracted heat borehole fell and the temperature of rejected heat borehole rose due to the lower evaporation temperature and the higher condensation temperature of the heat pump. Therefore it is important to control the ground temperature range.

Comparing this experiment results with the U-tube style ground heat exchanger, it is found that this type of GHE had a higher efficiency and a greater capability of extracting and rejecting heat. The extracted heat capacity is about 75~100W/m, while the rejected heat capacity is about 240~280W/m in both tested boreholes.

Seen from Figure 6, Temperatures fell obviously and finally balanced to a certain value in extracting heat. The balanced temperature is near 0°C at the outlet of GHE and near –2.5°C at the inlet. Through nine hours of continuous operation, the process was to be stabilized and balanced, meanwhile all temperatures were invariable in the condition of tested load. Whereas After just three hours, the outlet temperature of GHE was about 4°C and the inlet temperature was about 2°C. The power consumption was lower and the COP was more reasonable. Obviously a long time of continuous running will lead to the fall of efficiency of GSHP. Certainly, to solve a problem of long term of running, usually there are three ways, increasing the number of boreholes, taking an intermittent operation mode and changing the initial ground temperature. As a consequence, the Ground Thermal Energy Storage (GTES) technology is really able to change the initial ground temperature in a localized land.

Results of the heat rejected to the ground are shown in Figure 7. The temperatures begin to make the trend of balance after running nine hours as above. The balance time may be realized after a longer time in extracting heat than in rejecting heat due to a higher temperature difference and more load. It is speculated that it prolonged 1 or 2 hours and the balanced temperature is between 35°C and 40°C. Actually the balance time lies on the load. Therefore the quantity of the boreholes must be magnified or the heat transfer must be enhanced to keep the need of the load and the heat exchange capacity. We should also optimize the intermittent operation of the system to restore the ground temperature and then to control the temperature trend.
Figure 8 shows both inlet and outlet temperatures of the condenser and the evaporator. Results implied that when the temperature of boreholes was balanced the temperature of heating and cooling fluid would balance, the condition of GSHP would keep in stabilization.

3.3 Different initial ground temperatures

As an example of verifying the effect of the initial ground temperatures, this experiment aims to study the variation and distribution of ground temperature at different initial ground temperatures. When the initial ground temperature is 11.5°C, all ground temperatures of the different depth in extracting heat borehole are shown in Fig.6. The temperatures of GHE seem to approach to a balance after near 9 hours of running.

Then, the borehole was exchanged to a rejecting heat borehole, and its ground temperature should be raised. The work aims to do another initial ground temperature test. After a period of heating, a few days interval was taken to deposit and release heat for a relative balance of temperature field. Then the initial ground temperature rises to near 14°C. The above test process of extracting heat was replicated in a new higher initial ground temperature. Results of temperature are shown in Fig.9. When the temperatures fall down to near the balance from an initial ground temperature of average 14°C, the process lasts about 7 hours. And the average equilibrium temperature is a little higher than that of the former process shown in Fig.6. As we known, besides the heat load, the balanced temperature mostly relies on the initial ground temperature. At a higher initial ground temperature a high quality of energy is able to make the extracting heat process short and the balanced temperature gets high. Conversely the low initial temperature is suitable to the cooling process. However, this will affect the performance of the GSHP system.

3.4 Comparison between extracting and rejecting heat in different size of boreholes

Figure 10 and 11 show that both extracted and rejected heat in the same ground heat exchanger (borehole) are different, because of the different ground temperature and the difference of heat transfer in both processes.

Usually, the temperature difference in rejecting heat process is much bigger than in extracting heat process in a conventional north area. In the test, it is found that in the 100# the rejected heat was about 23kW–26kW, the extracted heat is about 13kW–18kW, and their difference is more than 45% but in the 200# borehole the former was about 21.5kW–28.5kW, the latter was about 14kW–19.5 kW, the difference was also kepted in about 45%.

Otherwise, the comparison of the capacity between both boreholes in the same process of heat transfer was taken. As to the extraction, 200# borehole is better and can obtain heat 5%–15% more than 100# borehole. But as to the rejection both borehole heat exchangers are similar. Exactly, the 100# one is a little better above 20°C of
outlet temperature of GHE, while the 200# one a little better below the 20 °C. So the borehole size is an important factor for GSHP which should be optimized and should be selected by designers earnestly.

![Figure 10 Comparison of extracted heat](image1)

![Figure 11 Comparison of rejected heat](image2)

4. CONCLUSION

A new type of the screwed tube bundle in ground heat exchangers was presented to enhance the heat transfer in GHE. It can disturb the flow and increase the heat transfer surface of underground pipe for enhancement. The multidimensional flow can improve the heat transfer in a coaxial vertical borehole GHE. Meanwhile, it can shorten the scale of the boreholes and decrease the first cost of the GSHP system. This experiment indicated that the extracting heat capacity of one unit depth was about 75~100W/m and the rejecting heat capacity was about 240~280W/m. The rejecting heat is generally much more than the extracting heat in the same vertical borehole GHE.

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